

Thrust Stand Measurements of the Conical Theta Pinch FARAD Thruster

Ashley K. Hallock

Mechanical and Aerospace Engineering, Princeton University

Kurt A. Polzin

Marshall Space Flight Center, NASA

I. INTRODUCTION

Pulsed inductive thrusters [1] operate by discharging a short, high-current pulse through an inductive coil, producing a time-changing magnetic field that induces an electric field in accordance with Faraday's law. Propellant breaks down (ionizes) near the inductive coil, where the induced fields are sufficiently strong, and a current sheet forms with current flowing in the opposite direction to the current in the inductive coil. This creates a high magnetic pressure between the current loops which accelerates the current sheet and any entrained propellant away from the coil to produce thrust.

The requirement for pulsed inductive breakdown of neutral propellant imposes high energy demands. In the Faraday Accelerator with Radio-frequency Assisted Discharge (FARAD) [2], it was shown that a current sheet can be formed with ten times less energy by ionizing the neutral propellant through external means. The compact design of this thruster class avoids propellant injection from upstream nozzles and removes the high energy breakdown requirements by partially ionizing the propellant upstream of a flat inductive coil and transporting the partially-ionized plasma downstream via an applied magnetic field through a high angle turn to arrive at the face of the inductive coil. Because this design requires the plasma to execute a high-angle turn, a new geometry was suggested as an alternative way to bring the plasma and inductive coil closer together. This thruster variant, the Conical Theta Pinch Faraday Accelerator with Radio-frequency Assisted Discharge (CTP FARAD), utilizes a conical inductive coil to accommodate the natural diffusive path of the preionized propellant, eliminating the dependence on an applied magnetic field.

Previous studies [3, 4] investigated the conditions for optimum current sheet formation in this type of plasma thruster in a backfilled configuration, finding that the maximum total current in the plasma current sheet, the spatial distribution of the time-integral of the current density (current sheet "strength"), the velocity of the current sheet centroid, and its total translation distance reach a maximum with respect to a ratio of two controllable experimental parameters, the stored energy in the capacitor and the backfill pressure. Furthermore, the value of the optimum ratio of capacitor energy to backfill pressure remains constant within the error bars for operation at higher and lower capacitor energies.

The work presented here discusses modifications made to a CTP FARAD [3, 4] to optimize its performance and

to allow for direct thrust measurements under a wider range of experimental conditions. In a thrust stand configuration, the mass of injected propellant, the energy stored in the capacitor, and the geometry of the thruster are varied to determine their effect on the impulse. A maximum in propulsive efficiency is found with respect to the geometry, energy in the capacitors, and injected propellant mass. The trends in efficiency with respect to these parameters suggest that the impulse depends on a ratio of the capacitor energy to the propellant injection mass. This supports the idea that current sheet formation (dependent upon the capacitor energy and the backfill pressure in ratio) strongly impacts the achievable impulse. It is concluded that the optimization of the current sheet formation process can directly impact propulsive efficiency, highlighting the importance of optimizing current sheet formation in this type of thruster.

The following describes thrust stand measurements performed to determine how the initial energy stored in the capacitors, the mass of injected propellant, and the thruster geometry affect the thrust of a propulsion device employing a conical inductive coil in the presence of preionized propellant. A maximum in impulse is found with respect to these three experimentally controlled parameters. Dependencies on these experimental parameters are explained based upon dominant processes occurring during the formation of the current sheet, as well as the gasdynamic processes occurring within the volume of the cone as the current sheet is accelerated away from the conical inductive coil. The rest of this abstract is organized into sections describing the experiment and discussing trends in the resulting data.

II. EXPERIMENT AND RESULTS

To convert the backfilled experiment into a thrust stand-ready configuration, the driving circuit was compressed into a current switch that directly connects a capacitor to the current feed point on the inductive coil. It is well known that the efficiency of pulsed inductive-type plasma thrusters is limited by the ratio of the total change in circuit inductance to the initial circuit inductance (Lovberg criterion). For this reason, the external, or parasitic inductance in the various components is minimized by minimizing the length of conductive material between the capacitor, current switch, and inductive coil. This not only increases the initial current rise rate in the driving circuit, but allows for the more compact design

required for practical thrust stand adaptation.

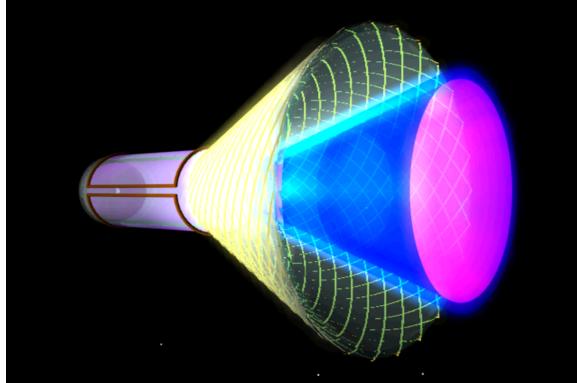


FIG. 1: CTP-FARAD: preionization chamber on the left leading to the inductive coil where the current sheet (blue) forms and accelerates away from the inductive coil, containing preionized propellant (pink).

The vacuum facility used in these experiments is a 25-ft. long stainless steel cylindrical vacuum chamber with a 9-ft. diameter. A base pressure of 5.7×10^{-7} torr is maintained by two 2400 l/s turbopumps and two 9500 l/s cryopumps. The VAHPER thrust stand, capable of supporting thruster masses up to 125 kg, producing between 100 μN and 1 N of thrust, was modified to accommodate the pulsed nature of the thruster. More information about the thrust stand in its steady-state configuration can be found in Ref. [5].

Impulse data were taken at a variety of capacitor energies ranging from 2 to 3 kV, a range of mass of injected propellant, and for three different half cone angles (10, 20, and 30 degrees). It is found that the impulse follows a similar trend as found in previous studies, namely

that the impulse is dependent upon the ratio of capacitor energy to propellant mass. The maximum in impulse is achieved for the same ratio of these two parameters (within the error bars), regardless of the independent value of either. The maximum in impulse with respect to half cone angle occurs for the intermediary value of 20 degrees.

III. DISCUSSION

It is found that the impulse of a pulsed inductive plasma thruster utilizing preionization is maximized for a particular ratio of the stored energy in the capacitor to the injected propellant mass. The fact that the impulse depends on the ratio of the initial stored energy to injected propellant mass agrees with previous current sheet studies, supporting the idea that a Townsend-like breakdown process strongly influences current sheet formation, and in turn, current sheet formation strongly affects the operational efficiency of the device. The optimum in half cone angle of the inductive coil can be explained in terms of a balance between the direct axial acceleration and the radial pinching contribution to thrust. From the trends in these data we conclude that operation at the correct ratio of capacitor energy to propellant mass is essential for efficient operation of pulsed inductive plasma thrusters employing a preionized propellant.

IV. ACKNOWLEDGEMENTS

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